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ABSTRACT

This paper develops a stimulus selection theory, based on an extensive review of previous research, which gives weight to context change or stimulus generalization decrement. The theory assumes no special compounding or configurational process, and accounts for the learning of successive discriminations without the addition of any special process. The theory predicts the relative rates of acquiring simultaneous and successive discrimination, including the "exceptions," and leads to correct predictions in a number of other paradigms. A computer simulation which embodies the context-sensitive theory confirms the predictions of the context theory of discrimination learning which has direct implications for research on types of learning process. Component, compound, and configurational learning emerge as summary descriptions of performance in different situations, but according to the present theory are neither styles nor distinct types of learning since data from the various situations are predicted by a single process. (Author/HMV)

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A Context-Sensitive Theory of Discrimination Learning

Douglas L. Medin

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A Context-Sensitive Theory of Discrimination Learning

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I. Stimulus vs. Response Selection

Consider an educated rat running in a T-maze on a brightness discrimination task. On each trial the rat runs down to the choice point. On some trials the reward is on the left and on others, reward is on the right. When the reward is on the left, a black stimulus is on the left at the choice point and a white stimulus is on the right; when reward is on the right, the black stimulus is on the right and the white is on the left. We observe an experienced rat make a correct response at the choice point on each of a series of trials even though the reward varies in position from trial to trial. Clearly the rat has "solved" the discrimination. But the task of the experimenter has just begun. He is faced with two alternative choices in describing the learning and performance of the rat in the T-maze and both the theoretical problems and rewards will depend on the alternative the experimenter selects. The prospective theorist can either characterize discrimination learning in terms of stimulus selection or response selection.

Before developing these two points of view it will be useful to introduce the two main variants of discrimination learning problems, the simultaneous and the successive discrimination paradigms, both shown in Figure 1. B and W stand for black and

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Insert Figure 1 about here

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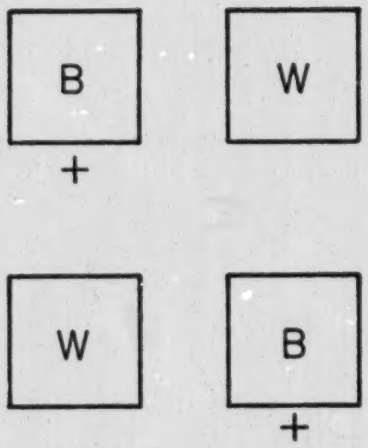
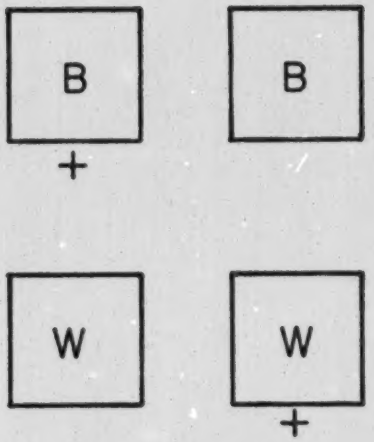
white. The panel on the left illustrates the example we used of the simultaneous discrimination paradigm, where the reward is associated with one stimulus value (in this case, black) regardless of its position. For the successive paradigm shown in the right panel, the stimuli on each trial are identical and the position of the reward depends upon which of the two stimulus configurations (BB or WW) is presented. Of course the simultaneous paradigm could also be described as one in which the reward position depends upon which configuration is presented.

One of the earlier mathematical models for discrimination learning (Gulliksen & Wolfle, 1938) described this situation in terms of responses to configurations. Gulliksen and Wolfle argued that it was very natural to conceive of the rat as "going left" and "going right." According to this orientation, these two responses come under the control of the appropriate stimulus configuration. Other mathematical learning models (Bush & Mosteller, 1951; Atkinson, 1960; Bush, 1963; Sternberg, 1963) have preferred a response selection characterization, perhaps because of its elegant simplicity and perhaps also because of the strong tradition of psychologists to speak in terms of reinforcing responses. For either simultaneous or successive discriminations, there are two stimulus settings (BW and WB or BB and WW) and two responses

2a



Simultaneous



Successive

and learning can be described succinctly in terms of the probability of a left (or right) response given a particular stimulus setting.

While response selection theories seem logical, it may be equally plausible to describe a discrimination task in terms of stimulus selection. For example, the simultaneous discrimination of Figure 1 could be conceived in terms of learning to choose black and avoid white regardless of their position. Spences's (1936) theory of discrimination learning is an example of this approach. According to Spence, the cues of Black, White, Left and Right all acquire habit strength and the responses are determined by the stimulus complex of highest strength.

These two distinct conceptions of the learning process have given rise to considerable experimental controversy which has served to point out serious difficulties with either approach. Let me briefly summarize some of the key findings. Nissen (1950) trained chimpanzees on a black-white simultaneous arrangement with the stimuli separated either in the usual horizontal orientation or in a vertical plane. A given animal was trained with a single orientation (e.g., left,right) and then given transfer tests with the stimuli appearing in the other orientation (e.g., up,down). The chimpanzees showed excellent but not perfect transfer of the discrimination across orientations. A response selection theory would have no basis for predicting above chance transfer since during training the subject would either learn when to go left or right or when to go up or down and the new stimulus

configurations were orthogonal to the old. A stimulus selection view would directly predict the transfer since if a chimpanzee learned to choose black during training, he should choose black during transfer regardless of its orientation. The only difficulty might be that a stimulus selection theory might predict that transfer should have been perfect, which it clearly was not.

Babb (1950) trained rats on a black-white simultaneous discrimination and then gave transfer tests involving two black (BB) or two white (WW) stimuli. He observed that his subjects responded quickly for two positive stimuli but slowly if at all for two negative stimuli. A stimulus selection theory would predict just this effect but a response selection theory would imply no differences in reaction to these two situations.

Referring again to Figure 1, response selection and stimulus selection theories would tend to differ in terms of the relative rates of acquisition of simultaneous and successive discriminations. According to a response selection theory, since BW and WB (simultaneous) should be less distinctive situations than BB and WW (successive), simultaneous discriminations should be more difficult than successive discrimination problems. However, if we think in terms of stimulus selection, for the successive problem Left, Right, Black, and White are rewarded equally often and it's difficult to see how a successive discrimination could be solved. In fact, Spence's theory as originally presented would predict that the successive problem is insoluable. This awkward fact can be averted by assuming (as Spence, 1952 did) that subjects

may form compounds of stimuli (e.g., white and left) under some circumstances. Thus the successive problem in Figure 1 would be solved by learning to approach "black-on-the-left" and "white-on-the-right." Whatever else one thinks of this modification it would seem that stimulus selection theories lead to the prediction that simultaneous discriminations should be easier than successive discriminations. Although there are a few exceptions which we shall presently consider, the weight of evidence (see Sutherland and Mackintosh, 1971) is strong in showing that simultaneous discriminations are mastered more easily than successive discriminations.

The empirical evidence has tended almost uniformly to support stimulus selection over response selection models and recent discrimination learning models (e.g., Zeaman & House, 1963; Lovejoy, 1968; Sutherland and Mackintosh, 1971; Fisher and Zeaman, 1972) all fall under the framework of stimulus selection theories. However, a certain discomfort remains because the theoretical mechanisms (e.g., compounding) evoked to explain successive discrimination learning play little or no role in accounts of simultaneous discrimination learning. Although this is probably not a fatal problem, it would seem incumbent on such theories to explain more clearly the role of compounds in learning if the notion of compound is to be more than a convenient explanatory device. When does compounding come into play? How is it modified? Since our theories are to be about processes in organisms, the mechanisms that an animal has <u>available</u> to bring to bear on

a situation ought to be the same regardless of the paradigm under consideration. To be sure, the situation may modify what the experimenter observes but then, we need a theory relating mechanisms to particular situations.

In the remainder of this paper, a stimulus selection theory is developed which gives important weight to context change or stimulus generalization decrement. The theory assumes no special compounding or configurational process and accounts for the learning of successive discriminations without the addition of any special process. The theory predicts the relative rates of acquiring simultaneous and successive discrimination, including the "exceptions" and leads to correct predictions in a number of other paradigms. To lay the groundwork for the theory, in the following section we consider the idea of context change or stimulus generalization decrement in some detail.

II. Context Change

There seems to be increasing awareness that memory phenomena may have implications for theories of learning (e.g., Estes, 1973). Forgetting was more or less ignored in early treatment of learning, perhaps because some early experiments seemed to show so little of it. Indeed, if animals are trained in a situation, receive little interfering training during the retention interval, and are tested in a situation identical to the training situation, they demonstrate remarkable retention up to at least 2 years (Liddell, 1927).

But what happens when the training and test situations are

not identical? We know from countless stimulus generalization studies that performance varies directly with changes in the relevant cue or cues. Less plausible but equally clear is the finding that changes in seemingly irrelevant or "background" features of a situation alter performance. For example, as early as 1917, Carr showed that performance on a spatial discrimination in a maze is lowered by 1) increases and decreases in illumination, 2) a change in the experimenters position, 3) a change of position of the maze in the room, or 4) rotation of the maze.

These may seem like trivial or uninteresting effects but there is evidence that contextual variables will be given increased weight in theorizing. Zentall (1970) demonstrated that retroactive and proactive interference are strongly controlled by the similarity of the learning and interfering contexts. In the same theme Robbins and Meyer (1971) and Glendenning and Meyer (1971) found that retrograde amnesia and retroactive interference were more strongly related to similarity of motivational states rather than temporal order.

The idea that contextual variables affect performance is not new; indeed, it is so familiar that it has a special term "generalization decrement." Nor has this factor been ignored by discrimination learning theorists. Sutherland and Mackintosh(1971) states "when an animal learns to switch in a given analyzer, it learns to switch it in a given situation. The rat that has learned to respond in a jumping stand to a black-white differ-

ence will not show an increased tendency to control its responses by responding to brightness cues in totally different situations such as its home cage (p. 55)." Yet context change has not been formally represented in any recent discrimination learning models. In the theory to be presented, context change is promoted to a major status and the implications of this are explored.

III. A Theory of Context Change in Discrimination Learning

A. Assumptions

We shall begin by stating some general assumptions about context change without committing ourselves to any particular learning model. On a general level the presentation is biased toward some of the recent concepts of reinforcement as discussed by Estes (1969a,b,c). Later on, it will become useful to perform computer simulations, which, of necessity, must be stated in terms of an explicit learning model.

1) Learning is conceived of as a matter of acquiring associative information concerning stimuli and outcomes. The effect of reward is neither direct nor automatic. Instead of talking in terms of strengthening responses, discussion will be phrased in terms of information, feedback or learned expectations.

2) In general we would like to distinguish between a cue and the context in which it occurs. Roughly speaking, a cue is what the subject responds to while context refers to the stimulus situation in which the cue occurs. In the learning situations to be considered in this

paper one can afford to remain at this loose level of definition because most of the results are independent of what we call cue and what we call context.

3) The amount of association information or feedback available from a cue in a given context is reduced either by changes in the cue under consideration or its context. The similarity on a given dimension of one cue to another will be represented by a parameter whose value is between 0 and 1, with 1 corresponding to identity on that dimension and 0 corresponding to total dissimilarity. The reduction due to context change on a particular dimension will be represented in like manner.

4) The context or cue change decrements from the various dimensions are combined in a multiplicative manner to yield a single similarity measure. Thus the difference between a white triangle on the left and a black square on the right involves a difference in position (p), brightness (b), and form (f). Any information associated with the white triangle would generalize to the black square but would be reduced by these differences. If R is the information from a reward associated with the white triangle, then pbfR would be associated with the black square. The difference in information (ΔI) as a result of such a reward trial would be (1-pbf)R.

5. In a discrimination learning task involving two alternatives we assume that the greater the difference in feedback or expectation associated with the two alternatives on a trial, the faster will be learning to discriminate between them. This assumption is introduced for expository purposes only; we shall see that this assumption is almost always true for the particular model we examine, although one cannot prove this assumption to be generally true independent of a particular model.

B. Applications to Simultaneous and Successive Discriminations

To see how we intend to employ our assumption, it will be useful to refer to Figure 1. From this figure we will generate a matrix of stimulus similarities for first the simultaneous and then the successive paradigm. Table 1 is the similarity matrix for simultaneous discriminations. The main diagonal is, of course, the maximum similarity, identity. Looking across the

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Insert Table 1 about here

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first row, we see that black-left differs from black-right in position (p), from white-left in brightness (b), and from white-right in both brightness and position (bp). From this matrix, we can estimate the net difference in information between two alternatives after a choice has been made. We shall use the notation B_L to refer to black on the left, and so on.

Consider now a problem where the two stimulus settings (B_L-W_R and W_L-B_R) are randomly intermixed. For illustrative

	B_L	B_R	W_L	W_R
B_L	1	p	b	bp
B_R	p	1	bp	b
W_L	b	bp	1	p
W_R	bp	b	p	1

Table 1. Similarity matrix for the stimuli. The letters p and b are parameters for position and brightness similarity, respectively. B_L, B_R, W_L, and W_R stand for black on the left, black on the right, white on the left, and white on the right.

purposes we focus on B_L-W_R differences. On B_L-W_R trials whatever outcome which occurs will be associated with both stimuli but to different degrees. If B_L is chosen, the reward will be associated to B_L and to W_R but to a lesser degree to W_R because W_R differs from B_L in brightness and position. Behar (1962) gave monkeys a series of small trial problems where every few trials either the correct or incorrect stimulus was replaced by a new correct or new incorrect object. On shift trials, monkeys preferred the old incorrect object to the new objects if they had not responded to it in the previous problem. The fact that it had not been chosen previously indicates that the negative object was not highly preferred and therefore it is plausible that generalization from the series of correct responses to the other object before the change produced the preference for old incorrect over new objects. If W_R is chosen, nonreward will be associated with W_R and to a lesser extent, because of the brightness and position differences, to B_L. The effective information gain in either case is 1-bp.

Now consider what happens to the B_L-W_R difference on W_L-B_R trials. When B_R is chosen both B_L and W_R are associated with reward, the generalization to B_L being diminished by a position difference (p) and the generalization to W_R by a difference in brightness (b). Likewise nonreward is associated with B_L and W_R when W_L is chosen. The effective information gain is p-b in either case. We can see that the amount by which W_L-B_R training facilitates the B_L-W_R discrimination increases with position

similarity and decreases with brightness similarity.

Considering a response to both the B_L-W_R and the W_L-B_R settings the information gain (ΔI) will be 1-bp+p-b which factors into:

$$\Delta_I = (1+p)(1-b) \qquad (1)$$

From this we anticipate that simultaenous discrimination will be solved more rapidly, the greater the distinctiveness of the relevant cue (the smaller b) and the greater the similarity of the positional cues (the larger p). Evidence on the first point is so common that I will only cite MacCaslin (1954) who showed that brightness discrimination in rats was related to brightness similarity.

There is almost no data on the effects of position similarity on a nonspatial discrimination. Spiker and Lubker (1965) found that a 0-inch separation to be better than a 10-inch separation (edge to edge) of stimuli for a brightness discrimination with children in terms of trials to criterion (7.4 vs. 4.8) but the trend was not statistically reliable. Using rats in a jumping stand, Elias and Stein (1968) obtained clear position similarity effects. The 4-choice discrimination used either a 25/8-inch or a 45/8-inch center to center stimulus separation. A triangle-circle discrimination was mastered much more rapidly for the larger separation and a diamond-square discrimination produced evidence for learning only in the case of the larger stimulus separation.

The successive problem, shown in the right panel of Figure 1,

can also be examined in terms of Table 1. The information difference between B_L and B_R on B_L-B_R trials is equal to 1-p, and on W_L-W_R trials the information difference between B_L and B_R is bp-b. The latter term is negative and implies that W_L-W_R training would tend to interfere with the B_L-B_R performance, and more so, the greater the brightness similarity. (If b were equal to 1 then this term would be p-1 and the Δ_I would equal zero, implying an insoluable problem.) From the B_L-B_R and the W_L-W_R settings we find that the total information gain will be 1-p+bp-b which factors into:

$$\Delta_I = (1-p)(1-b). \qquad (2)$$

From equaltion 2 one would expect that performance on successive discrimination would decrease with both position and brightness similarity. MacCaslin (1954) has shown that brightness similarity impairs successive brightness discriminations.

As for the prediction that position similarity impairs successive discrimination, there is virtually no data. A nonsignificant trend in the predicted direction was reported by Spiker and Lubker (1965) in a study using children as subjects. I know of no relevant animal data.

One can use equations 1 and 2 to compare simultaneous and successive discriminations. Since (1) will be larger than (2) except for the case when p is zero (or b is 1), we are led to predict that simultaneous discriminations should be easier than successive discriminations which generally has been found (e.g., Spence, 1952; MacCaslin, 1954; Bitterman, Tyler, & Elam, 1955;

Warren & Barron, 1956; Lipsitt, 1961; Spiker & Lubker, 1965; Price & Spiker, 1967).

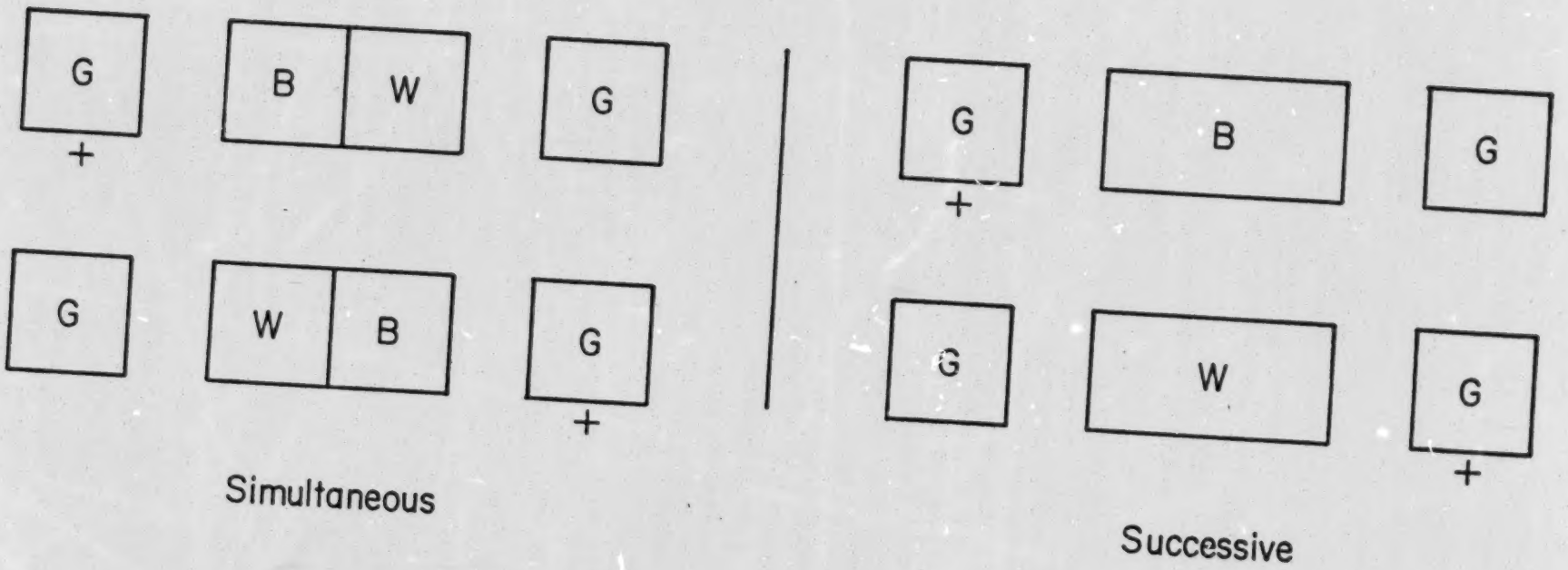
There is an interesting exception to this general rule: when the choice responses are not to the relevant cues directly, successive discriminations are found to be easier than simultaneous discrimination problems (e.g., Bitterman & Wodinsky, 1953; Wodinsky, Varley, & Bitterman, 1954; Bitterman, Tyler, & Elam, 1955; Lipsitt, 1961). An example of this situation taken from Bitterman and Wodinsky (1953) is shown in Figure 2.

Insert Figure 2 about here

Responses are to the grey stimuli rather than to the black and white cues. If we apply the logic for information differences between G_L and G_R on the top of either panel, we obtain 1-p for trials on the top setting and p-1 for trials on the bottom setting, for a net difference of zero. However, the center black and white stimuli differ between setting and introducing c for the similarity of the center contexts the G_L-G_R difference on the top remains 1-p for responses to the top setting and becomes c(p-1) for response to the bottom setting. The net difference then becomes

$$\Delta_I = (1-p)(1-c) . \qquad (3)$$

From equation 3 we expect that the rate of learning will increase with position distinctiveness and will increase the greater the difference in center contexts between the top and bottom settings of the discrimination. It seems plausible to me that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this difference would be greater for the successive discrimination than the simultaneous paradigm from which would follow the results that in these circumstances, successive discriminations are solved more rapidly.

Before we consider other detailed predictions from various paradigms, one should pause and note that the model as presented is not treating simultaneous and successive discriminations in any different manner. No new mechanisms are brought into play for one paradigm and not the other. Although this presentation may have built in some descriptive biases it is even the case that it has not been necessary to distinguish between cue and context. Equation 1 results whether we assume that black and white are cues and all else is context, or left and right are cues and all else context, or black plus left is one cue, white plus left another and so on. Whether this is a virtue or a flaw cannot be concluded just yet. Within this flexibility we can generate a surprising number of predictions for which there is quite good support.

C. Further predictions for simultaneous and successive discriminations

We now consider procedures where either irrelevant or redundant relevant cues are added to simultaneous and successive discriminations. Figure 3 displays discriminations where both size and brightness are relevant cues. We derive a measure of the net information gain exactly as before. For the simultaneous problem

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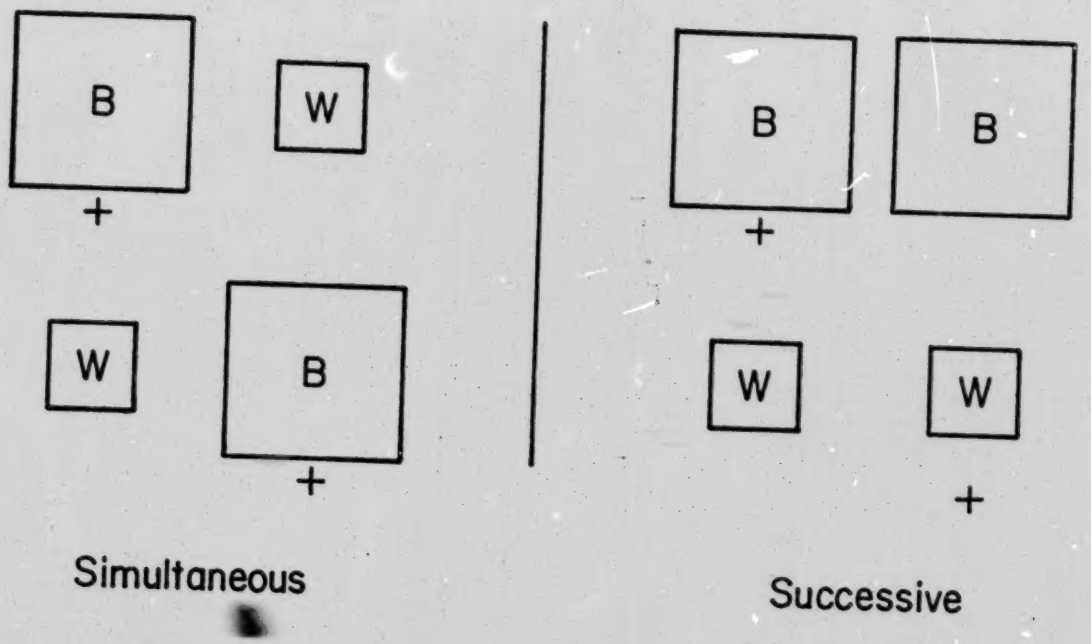
Insert Figure 3 about here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in the left panel the difference between the top two stimuli from the top setting is 1-pSb, where s represents the size similarity parameter, and the difference between the top two stimuli owing to generalization from a trial on the bottom setting is p-Sb so that

$$\Delta_I = (1+p)(1-Sb). \quad (4)$$

By similar means we can find the value for the successive paradigm in the right panel of Figure 3 to be

$$\Delta_I = (1-p)(1-Sb). \quad (5)$$

Comparing equations 4 and 5 to equations 1 and 2, we conclude that the information gain will be greater and the discrimination will be solved more quickly when redundant relevant cues are present. This prediction has been repeatedly confiremd for the simultaneous discriminations (see Bower & Trabasso, for a review) and has also been demonstrated for successive discriminations (Warren, 1964; Lubker, 1969).

Irrelevant dimensions may be added to these discriminations in a number of ways. In Figure 4, the irrelevant size cue is confounded with spatial position. Deriving the value for net

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Insert Figure 4 about here

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information gain from the two settings we find

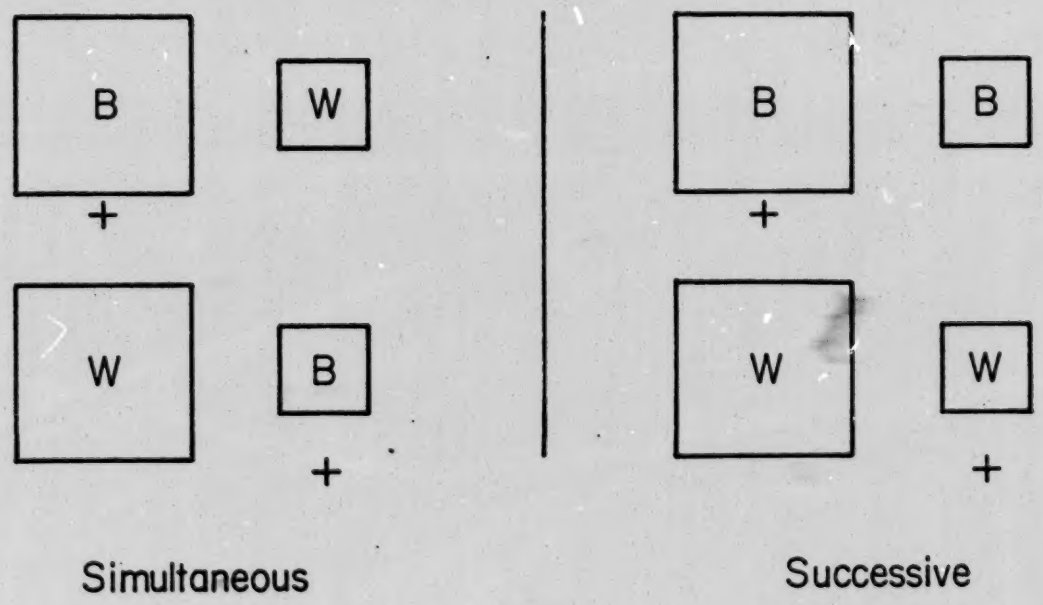
$$\Delta_I = (1+Sp)(1-b) \quad (6)$$

for the simultaneous case and

$$\Delta_I = (1-Sp)(1-b) \quad (7)$$

for the successive problem. Again referring to equations 1 and 2

16a



one can see that simultaneous discriminations should be impaired by the spatially confounded irrelevant cue but that successive should be facilitated by the irrelevant size cue. Both these predictions were confirmed in a single experiment with children by Price and Spiker (1967).

By adding two new settings to the basic paradigms one can produce irrelevant cues not confounded with spatial position as is shown in Figure 5.

Insert Figure 5 about here

The procedure for deriving the net information difference is the same as before with the difference being derived from all four settings. The result for the simultaneous paradigm is

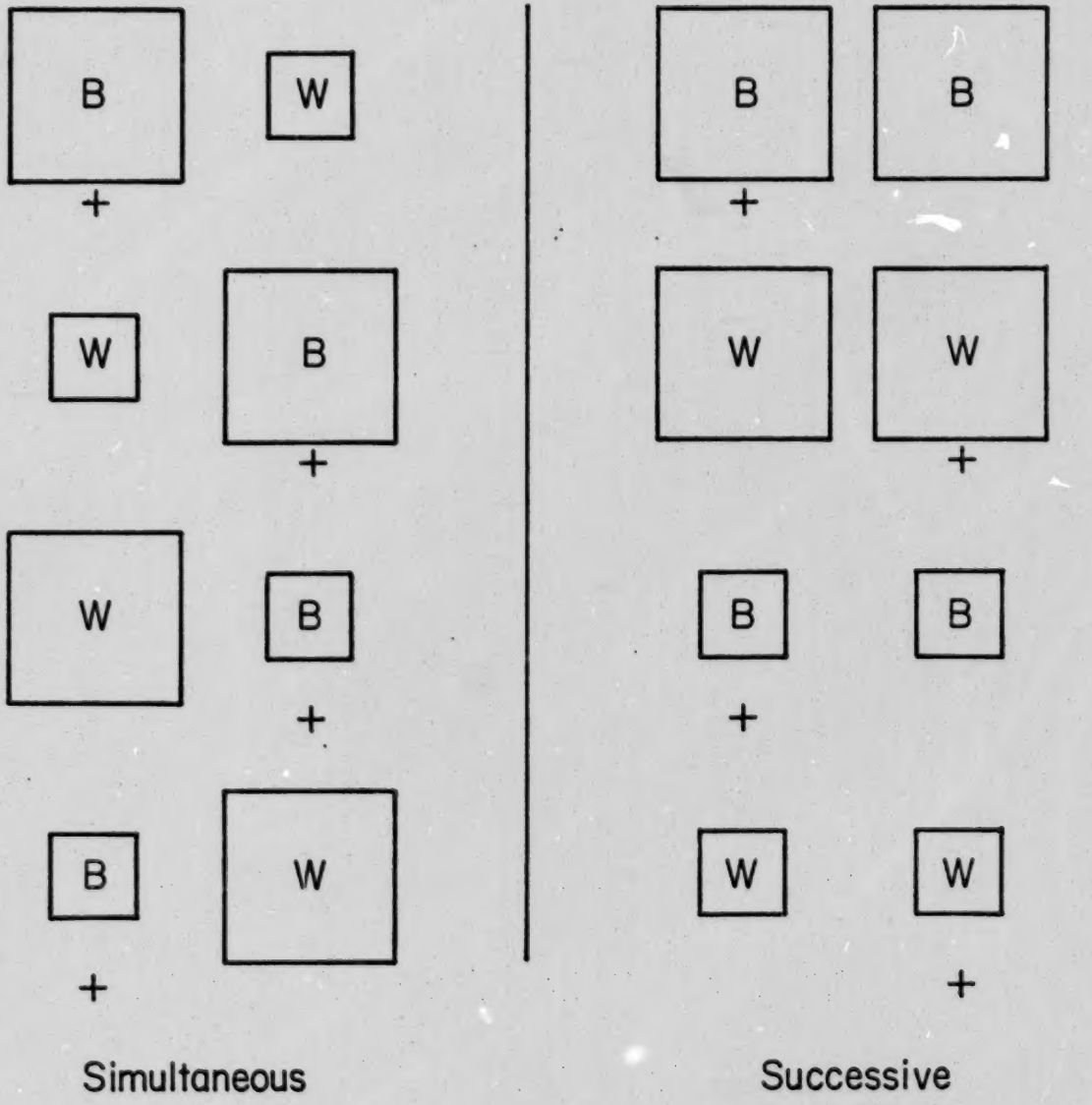
$$\Delta_I = (1+p)(1-b)(1+S) \qquad (8)$$

and for the successive paradigm it is

$$\Delta_I = (1-p)(1-b)(1+S). \qquad (9)$$

Here the proper control comparison is a four-setting problem where S=1, from which we can predict that the irrelevant dimension not confounded with position will impair performance on both simultaneous and successive discriminations. For simultaneous problems favorable evidence on this prediction has been obtained by Lawrence and Mason (1955), Lubker (1967), and Price and Spiker (1967), that latter study showing that the more distinctive the irrelevant cue, the greater the impairment. As far as I can ascertain this prediction has been assessed but once in the successive paradigm and the result was that children's performance

17a



was worse in the presence of irrelevant cues (Tragakis, 1968).

Another choice point in introducing irrelevant dimensions is deciding whether they shall vary within or between dimensions. In the left panel of Figure 6 the irrelevant brightness dimension varies between settings while it varies within settings in

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Insert Figure 6 about here
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in the right panel. The values for net information gain are

$$\Delta_I = 1-Sp+bp-Sb \qquad (10)$$

for the variable between-problem and

$$\Delta_I = 1-Sbp+bp-S \qquad (11)$$

for the variable-within problem. Comparing equations 10 and 11 we find that 10 exceeds 11 by $S(1-p)(1-b)$. Since this value is positive, variable-between problems should be easier than variable-within discriminations and this difference should increase with size similarity. At the extreme case of $S=1$, the variable-between problem becomes a successive discrimination, while the variable-within problem becomes insoluable. Spiker and Lubker (1964) found that size similarity did hurt performance, that variable-between was easier than variable-within, and that this difference increased as size similarity increased.

A more usual manner of comparing variable-within versus variable-between irrelevant cues uses four stimulus settings as in Figure 7. The information analysis now yields the same

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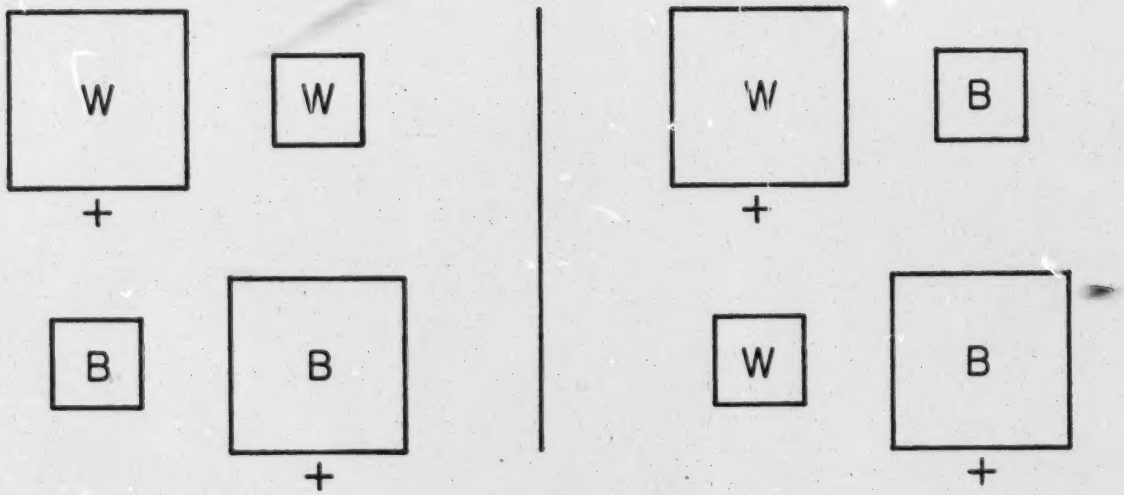
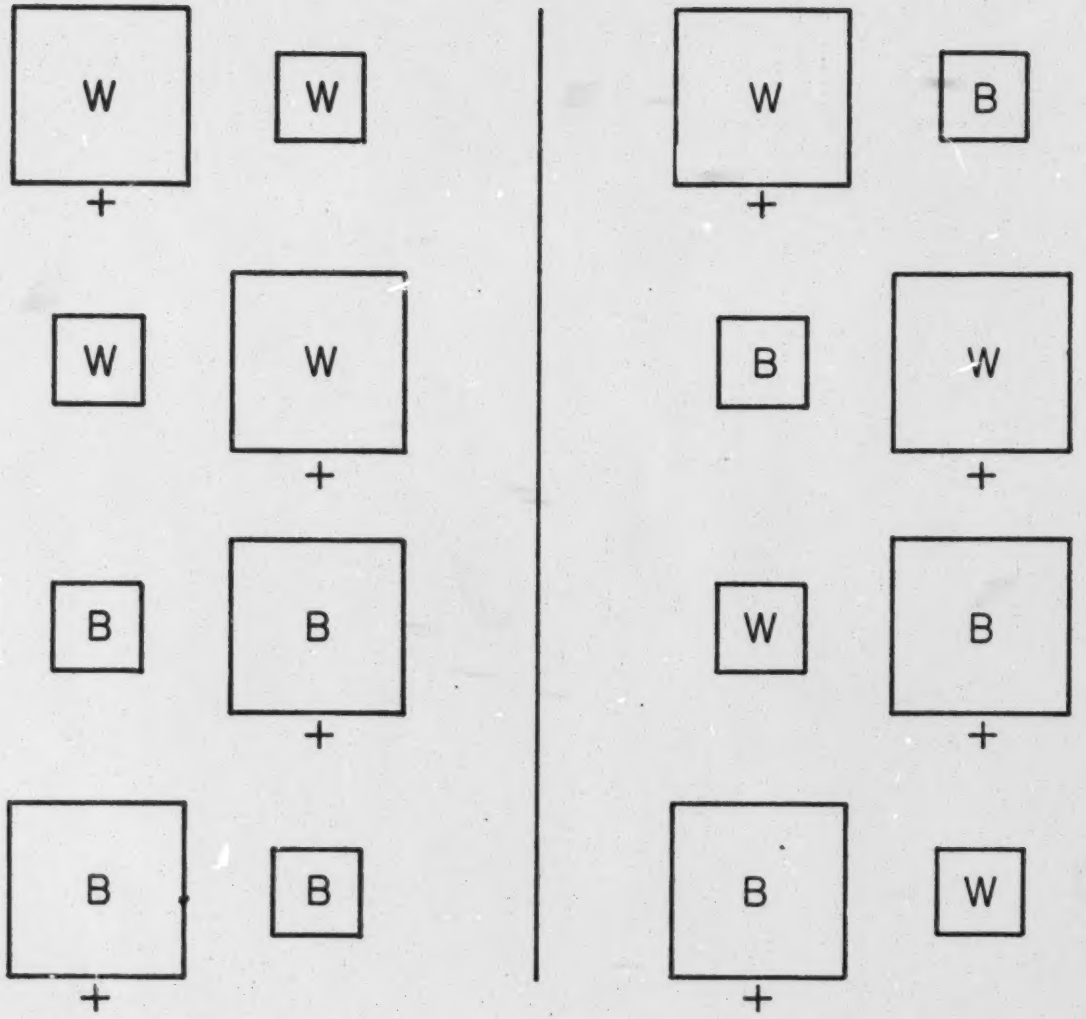
Insert Figure 7 about here



Variable Between

Variable Within



Variable Between

Variable Within

equation for either manipulation

$$\Delta_I = (1-S)(1+p)(1+b), \qquad (12)$$

and consequently we would predict no differences in these two paradigms. However, in making this comparison we run into a serious problem. We cannot assume that a given subject has equal preferences for white and black stimuli. In other situations one can perform a counterbalancing manipulation and hope preferences are cancelled out. The fact that the correct stimuli are sometimes white and sometimes black does not mean that preferences are controlled for. We shall confirm this problem in discussing the computer simulations and for the moment equivocate by stating that one cannot make a clear-cut prediction. Neither are the relevant data so clear. Lubker (1964) and Sheep and Gray (1971), obtained some data favoring variable-between over variable-within but Evans and Beedle (1970) found no difference for retarded girls and variable-within better than variable-between for retarded boys.

This last prediction aside, our analysis appears to be quite promising since a number of predictions which are not intuitively obvious have been confirmed, and we have failed to note any fatal difficulties in our approach. We turn now to other paradigms and controversies for which the model is applicable.

Further Applications

Appreciable interest has centered around component versus configurational learning, which loosely corresponds to a stimulus versus response selection approach. Figure 8 shows the design

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Insert Figure 8 about here
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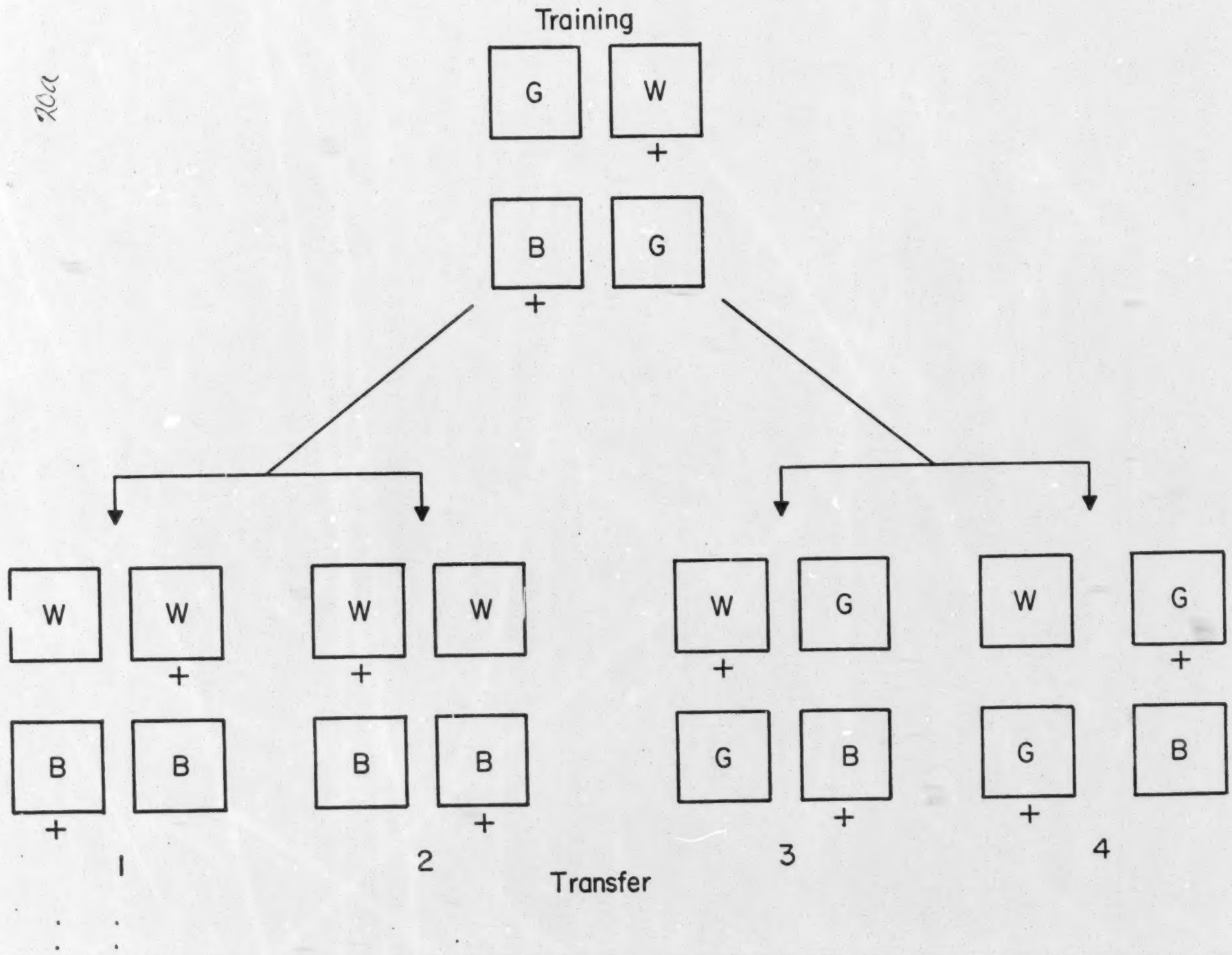
of an experiment by Birch and Vandenberg (1955) which appeared to yield contradictory results. Subjects were trained on the discrimination G_L-W_R and B_L-G_R shown at the top of the figure which could be solved either by learning that black and white were correct or by learning to go right for a bright array and left for a dark array. The lower left problems (1 and 2) were tests to see if learning has been configuration. If subjects had learned to choose right for light stimuli and left for dark stimuli, then subjects given transfer condition 1 should perform better than subjects given transfer condition 2 at the start of transfer. This is what Birch and Vandenberg observed. Likewise one might expect that subjects would do better in transfer situation 4 than in 3 if they had learned "light-go right, dark-go left." Yet subjects performed better on task 3 than 4 as if they had learned to choose black and white rather than learning a configuration.

We can apply the present model to these data by measuring the similarity of the training and transfer situations. First taking transfer situations 1 and 2 the W_R-W_L difference from the G_L-W_R setting is 1-p and from the B_L-G_R setting is pb-b, yield a new difference of (1-p)(1-b) which is positive so that the model predicts that situation 1 will have an advantage over situation 2 at the start of transfer. Similar empirical results have been reported by Johnson (1962) and Lubker (1964).


Training
G
W
+
B
G
+
W
W
+
B
B
+
1
W
W
+
B
B
+
2
W
G
+
G
B
+
3
W
G
+
G
B
+
4
Transfer

Transfer in situations 3 and 4 is slightly more complicated because there is both black-gray and white-gray differences which we will assume to be equal and a black-white difference which would be expected to be larger than the other differences. We represent the black-white differences by b and the black-gray and white-gray differences by b+X, where X is greater than zero and less than 1-b. That is, gray and black are assumed to be more similar than white and black. Now one can obtain that the W_L-G_R difference is equal to [p(1-b)-X(1-p)] and since X is less than 1-b, the difference in initial information must be such that

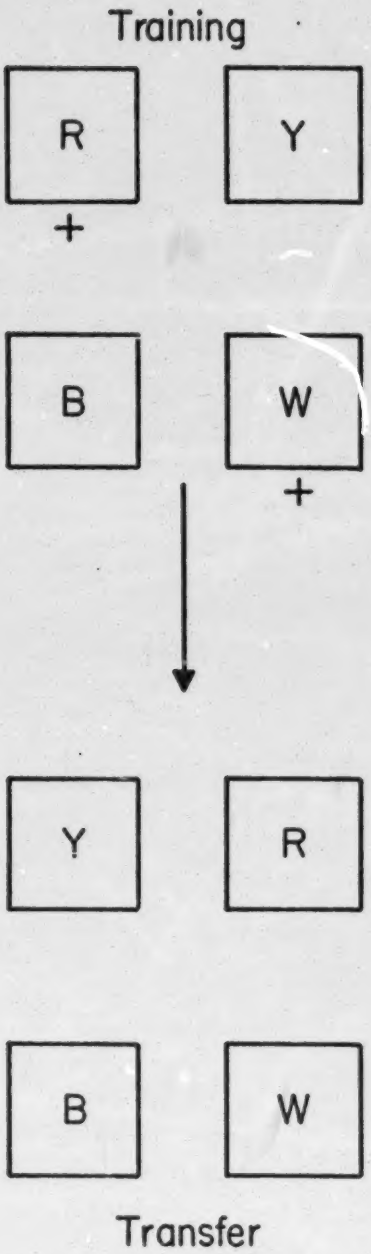
$$\Delta_I > (1-b)(2p-1). \qquad (13)$$

Therefore whenever p is greater than one half we would predict better transfer to situation 3 than 4. This means that under this restriction both of the main results of Birch and Vandenberg follow from the model.

A related more frequently used paradigm is shown in Figure 9.

Insert Figure 9 about here

R, Y, B, and W stand for Red, Yellow, Black, and White but there is no special significance to these particular colors. After training on the top problem subjects are given transfer to both stimulus arrangements. Experimenters then measure whether subjects continue to select the same rewarded stimuli (Red and White) or whether they select the same responses to the stimulus configurations. To obtain transfer predictions we use C for color similarity and use C_w and C_b to distinguish within and between


Training
R
Y
+
B
W
+
Y
R
B
W
Transfer

setting color similarity since that has been an experimental variable. At the beginning of transfer the difference in reward information between R_R and Y_L would be

$$\Delta_I = p - C_w + C_b - pC_b. \qquad (14)$$

From equation 14 we predict that a stimulus selection solution (choice of red) will 1) decrease with within setting color similarity; 2) increase with between pair similarity, and 3) increase with position similarity. I know of no evidence on the second and third predictions but favorable results on the first prediction have been reported by Turbeville, Calvin, and Bitterman, (1952); White and Spiker (1960); Teas and Bitterman (1962); and Zeiler and Paul (1965).

Note that in terms of the model, compound and configurational solution modes are more properly thought of as properties of stimuli than of subjects as such. If the within pair similarity varies in the two settings, then it is quite possible that one might obtain "confugurational responding" for one pair and a "component solution" for the other setting pair. This outcome has been observed by Liu and Zeiler (1968) and Campione, McGrath, and Rabinowitz (1971). Developmental shifts in patterns of responding (e.g., Zeiler, 1964) might simply reflect shifts in the salience of particular dimensions, such as a decrease in the salience of position cues.

Quite complicated variations of simultaneous and successive discriminations have been shown to be soluable. Figures 10 and and 11 show what might be called conditional simultaneous and

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Insert Figures 10 and 11 about here
---

conditional successive discriminations. The conditional simultaneous problem can be described as large is correct for white stimuli, small is correct for black stimuli. The information value equation for this paradigm is

$$\Delta_I = (1+p)(1-S)(1-b). \qquad (15)$$

Thus there is a net gain of information on this problem which Lashley (1958) long ago showed was soluable. It remains for the computer simulation to show that we can predict that this problem is soluable. Hoyt (1960, 1962) found that brightness distinctively facilitates performance on this problem as equation 15 implies.

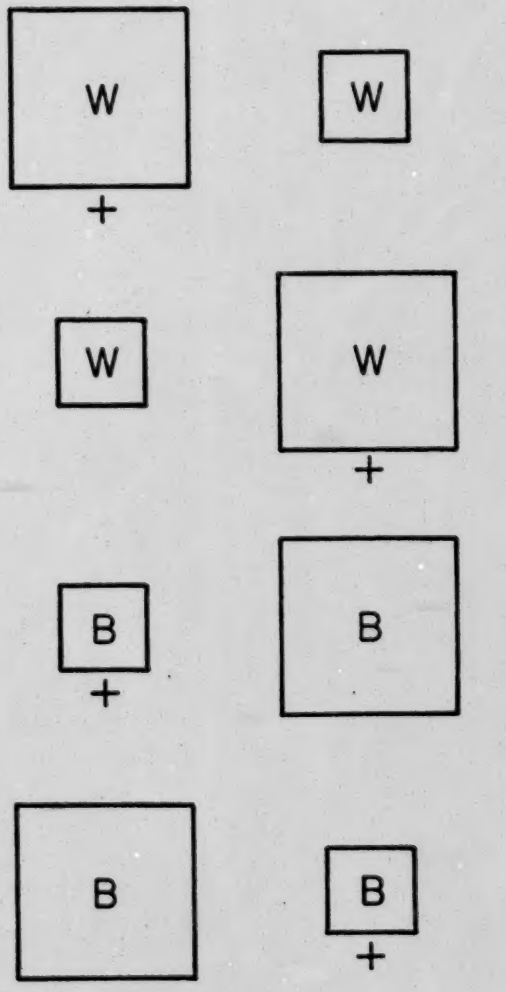
The conditional successive problem in Figure 11 can be solved as for small stimuli; black-go left, white-go right while for large stimuli, black-go right and white-go left. The appropriate equation is

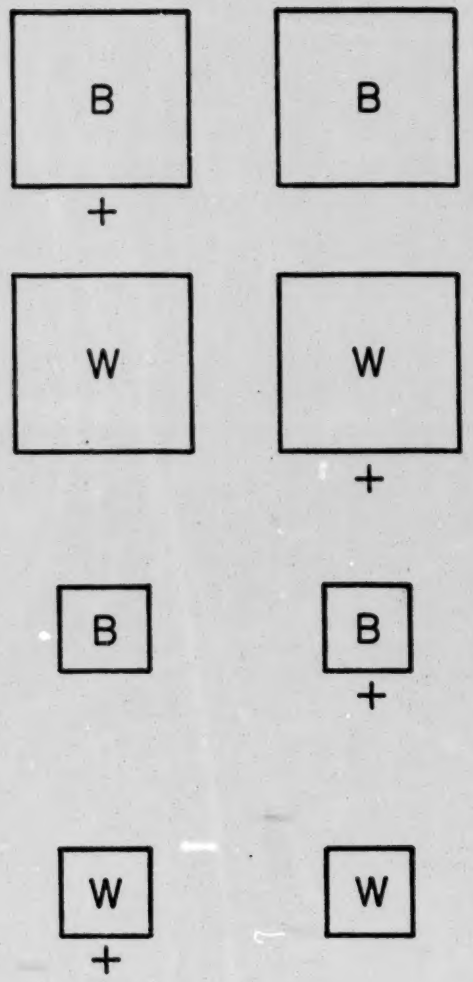
$$\Delta_I = (1-p)(1-S)(1-b). \qquad (16)$$

Flagg (1973) ran monkeys on the paradigm shown in Figure 11 and found that the problem was difficult but soluable. We demonstrate that this can be predicted from the model in the computer simulation.

More taxing of the theory is the transverse patterning problem where stimulus A is correct in one pair and incorrect in another, B is correct in one and incorrect in another, and C is correct in one and incorrect in another - i.e., A^+B^-, B^+C^-, C^+A^-.

23a




B
B
+
W
W
+
B
B
+
W
W
+
Conditional
Succesive

These problems are soluable by chimpanzees (e.g., Nissen, 1942) but would not follow from the development of the theory up to here. However, these data may be very much in the spirit of a context-sensitive theory. To predict that the transverse patterning could be mastered if A in the presence of B was a slightly different context from A in the presence of C. This could account both for the solution and the difficulty of transverse pattern problems.

Before summing up, we turn to a computer simulation which embodies the context-sensitive theory. We do this to get away from simply talking of information which is a useful device for drawing out predictions but too imprecise to have much rigor.

IV. Computer Simulation of the Model

Since the feedback or scanning model has been discussed elsewhere (Estes, 1962, 1966), only modifications will be discussed here. The model assumes that on a given trial, the subject scans the available choices generating a feedback (covert prediction of reward value) for each choice and makes the response which he predicts will yield the highest feedback. If the subject responds to choice i on Trial n, and is rewarded, feedback k for choice i changes with the following linear operation:

$$F_{i,n+1} = F_{i,n} + (1-F_{i,n})\theta. \qquad (15)$$

If the subject responds to cue i on Trial n and is not rewarded, the linear operator applies as follows:

$$F_{i,n+1} = F_{i,n}(1-\theta). \qquad (16)$$

The feedback for all choice alternatives changes on each trial

as a function of their similarity to the alternative chosen. If S_{ij} is to total similarity (obtained by multiplying stimulus similarity parameters from each of the dimensions) of choice j to choice i, then if choice i is selected feedback for choice i changes by θ and feedback for choice j changes by $S_{ij}\theta$. This applies equally for within and between setting cues.

Feedback values for choices are combined to yield overt responses in a manner consistent with the discussion above and as treated by Estes (1962). Since we shall only be looking at two-choice situations, only its equation shall be given:

$$P_A = \frac{F_a(1-F_b)}{F_a(1-F_b)+F_b(1-F_a)}, \qquad (17)$$

where P_a is the probability of selecting choice A over choice B given feedback values F_a and F_b. Note that when feedback for a choice reaches unity it will always be selected independent of the feedback for the other choice (unless its value is also unity).

To avoid unnecessary redundancy, the results from simulations will only be briefly presented. The format will be a summary statement, the parameters used (b,p,and S from before plus a learning rate parameter,θ), the results, and a reference equation and figure. For some novel findings a little more discussion will be provided. The initial feedback values for each of the choices was set at .50. In each case 50 statistical subjects were run for 20 trials on each setting or until learning was complete.

Statement	Parameters	Results [Mean Errors]	Equation	Figure
Simultaneous:				
1. Position similarity helps	θ=.50 b=.20,p=.30	2.06	1	1(left)
	b=.20,p=.70	1.48		
2. Brightness similarity hurts	θ=.50 b=.00,p=.30	1.46	1	1(left)
	b=.20,p=.30	2.06		
	b=.50,p=.30	7.14		
3. Redundant relevant cues helps	θ=.50 b=.20,p=.30,S=1.00	2.06	4	3(left)
	b=.20,p=.30,S=.30	1.66		
Successive:				
1. Position similarity hurts	θ=.50 b=.20,p=.30	5.52	2	1(right)
	b=.20,p=.50	17.30		
2. Brightness similarity hurts	θ=.50 b=.00,p=.30	2.72	2	1(right)
	b=.20,p=.30	5.52		
	b=.50,p=.30	38.26		
3. Redundant relevant cue helps	θ=.50 b=.20,p=.30,S=1.00	5.52	5	3(right)
	b=.20,p=.30,S=.30	3.64		

Statement	Parameters	Results [Mean Errors]	Equation	Figure
Simultaneous vs. Successive				
1. Simultaneous easier than successive and more so as the distinctiveness of the relevant cue lessens as found by MacCaslin (1954)	θ=.50 p=.30 b=.00	succ./sim.=1.86	1,2	1
	b=.20	succ./sim.=2.68		
	b=.50	succ./sim.=5.36		
2. Irrelevant cues confounded with position hurts simultaneous and helps successive:	θ=.50			
Simultaneous	b=.20,p=.30,S=1.00	2.06	6	4(left)
	b=.20,p=.30,S=.30	2.90		
Successive	b=.20,p=.30,S=1.00	5.52	7	4(right)
	b=.20,p=.30,S=.30	3.40		
3. Irrelevant cues not confounded with position hurts both simultaneous and successive:	θ=.50			
Simultaneous	b=.20,p=.30,S=1.00	1.96	8	5(left)
	b=.20,p=.30,S=.30	3.66		
Successive	b=.20,p=.30,S=1.00	4.74	9	5(right)
	b=.20,p=.30,S=.30	11.68		

Statement	Parameters	Results [Mean Errors]	Equation	Figur
Two-setting Variable-Between and Variable-Within Irrelevant Cues				
1. Similarity hurts	θ=.25			
variable-between	b=.40,p=.10,S=.10	4.12	10	69lef
	b=.40,p=.10,S=.40	4.40		
and variable-within	b=.10,p=.40,S=.10	4.58	11	6(rig
	b=.10,p=.40,S=.40	8.12		
2. Variable between easier and more so as similarity increases	same as above			
	S=.10 Within/Between	1.12	10	6
	S=.40 Within/Between	1.85	11	
Four-setting Variable-Between versus Variable-Within Irrelevant Cues				
1. No difference predicted if initial preferences (feedback values) are equal	θ=.50			
Variable-Between	b=.20,p=.20,S=.20	4.22	12	7(left
Variable-Within	b=.20,p=.20,S=.20	4.10	12	7(righ
2. Initial preferences favor variable between	θ=.50			
Variable-Between	b=.20,p=.20,S=.20	4.06	12	7(left
Variable-Within	b=.20,p=.20,S=.20	4.44	12	7(righ

$F_{i,0}$ = .70 for all black cues
$F_{i,0}$ = .30 for all white cues

Statement	Parameters	Results [Mean Errors]	Equation	Figure
Conditional Simultaneous and Conditional Successive				
1. Conditional Simultaneous will be easier than conditional Successive	θ=.50			
Simultaneous	b=.20,p=.20,S=.20	9.6	15	10
Successive	b=.20,p=.20,S=.20	25.36(in 80 trials and still not solved)	16	11
2. Both are soluable				
Simultaneous	see above			
Successive	θ=.80			
	b=.00,p=.00,S=.00	2.48	16	11

In summary, the computer simulation confirms the predictions of the context theory of discrimination learning. The information equations are useful for expository purposes and to obtain a short-cut view of various paradigms but the computer simulation is really the proof of the pudding. The simulation is quite general and can be used to investigate a number of alternative paradigms and conditions, including probabilistic reinforcement tasks and n-alternative discriminations for which the utility of the information equations is less clear. Space prevents an exploration of some of these other results, although I hope to report on them in the near

future. Overall no major shortcomings in the model have been evidenced and it is appropriate to turn to a discussion of alternative theories and the implications of the present theory.

IV Discussion

The introduction has served to show that most previous discrimination learning models have implied different processes operating in simultaneous and successive problem learning. Other theorists have discussed generalization decrement but have not incorporated this concept into models. The stimulus-interaction hypothesis of Spiker (1963, 1970) which is formulated from a Hull-Spence orientation comes closest to the present theory. Spiker assumes that the habit strength accruing to a stimulus component from direct reinforcement of a compound will be reduced when that component appears in a different compound and that the amount of reduction will increase with the average dissimilarity between the corresponding elements in the two stimulus compounds. Aside from being formulated from a Hull-Spence point of view, Spiker's theory differs from the present theory in that Spiker uses an average dissimilarity measure rather than a product rule for combining dissimilarities. The averaging rule leads to two clear incorrect predictions: 1) that adding irrelevant nonspatial dimensions to successive discriminations will have no effect; and 2) that a conditional successive discrimination is insoluable. The product measure of similarity contains neither defect and is probably simpler to work with.

The context-sensitive theory has direct implications for

research on "types" of learning process. Component, compound, and configurational learning emerge as summary descriptions of performance in different situations but according to the present theory are neither styles nor distinct types of learning since data from the various situations are predicted by a single process. It may be important to revise our thinking about compounds, components, and configurations at the very least from the point of view of what might be evidence for one or another process.

Although the present model has had wide-ranging success in predicting experimental results, it is general enough and simple enough that its ideas might be incorporated into current discrimination models. I have only made the barest beginnings on this task but my guess is that some awkward assumptions may be dropped and the range of applicability of these theories will be broadened. Since the distinction between cue and context is not tightly drawn in the present framework (at least for these situations) there is room for a considerable range in assumptions concerning selectivity in learning and performance (i.e., defining the functional cues).